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THE USE OF CONTACT SPONGE METHOD TO MEASURE WATER ABSORPTION IN EARTHEN HERITAGE TREATED WITH WATER REPELLENTS

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Abstract: Earthen heritage represents an important legacy regarding construction history and technological development, with a significant cultural value that must be preserved. According to UNESCO, around 10% of the World Heritage is built using earth, and 57% of these heritage structures are in danger. Although the interest regarding earthen heritage has grown in the last few years, there is still a significant lack of knowledge in terms of material characterization, especially from conservation science point-of-view. In particular, tests regarding water absorption are always difficult to perform with a material that changes completely when in contact with water. Indeed, due to the presence of clay particles, a normal capillarity test is almost impossible to perform. Moreover, water is responsible for a significant number of degradation phenomena often found in earthen heritage. As a result, there is an urgent need to develop suitable water repellent treatments and to evaluate their efficiency. For this reason, this study focuses on the contact sponge method to assess water absorption rates for adobe and for rammed earth specimens treated with three different water repellents – siloxane, linseed oil, and beeswax. Two sets of specimens were prepared and tested, showing that this method can represent an effective way to measure initial water absorption in earthen materials, and promising results from the tested water repellent treatments were found.

Keywords: earthen heritage; contact sponge method; water absorption; water repellents

1. Introduction

Using earth as a construction material is a millenary practice. Vernacular architecture, as well as archaeological sites found in North Africa, Middle East or South America show how ancient civilizations used earth to build houses and monuments [1]. Many different types of earthen construction technologies (e.g. adobe and rammed earth) have been developed based on locally available materials (e.g. soil, sand, lime, natural fibers) and traditional know-how [2]. Adobe, also known as mudbrick, consists in molding a mixture of soil and water (workable enough to be molded) within a brick shape and is left to dry under the sun. In turn, rammed earth involves compacting soil into wooden formworks (Figure 1) [3]. So, different earthen building techniques can be found all around the world according to the geographical location, type of soils and local weather conditions [4].

1.1. Earthen construction overview

References to earthen architecture can be found in Vitruvius' *De Architectura*, where the adobe technique is described, as a mixture of soil and straw, and it is considered as the most suitable raw material for construction. It also suggests the best period for the preparation of the bricks and advice for rain protection [1]. In Greece, references to adobe masonry were made by Pausania, who described the rebuilding of different structures after their destruction by the Spartans, and by Plinius who explained two types of earthen constructions: adobe and rammed earth [1]. One of the most remarkable examples of earthen construction is Chan Chan city – the largest adobe urban complex in the world, located on the northern coast of Peru (Figure 1) [5].

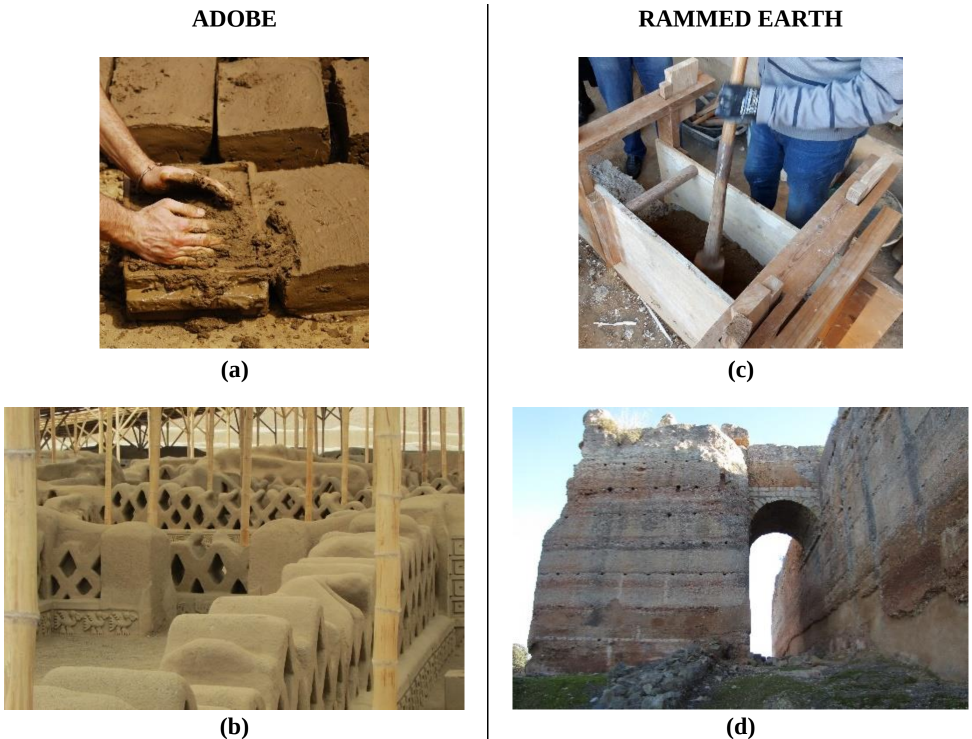


Figure 1: Earthen construction: (a) Adobe technique; (b) Chan Chan archaeological site, Peru (construction made with adobe blocks); (c) Rammed earth technique; (d) Paderne Castle, Portugal (construction made with rammed earth).

In Portugal, earthen architecture has an important expression, being identified through a relevant heritage across the country. The origin of this type of construction in Portugal is Pre-historic, likely from the Middle Palaeolithic Age when the first modern humans began to settle down [6], [7].

Moreover, the Muslim occupation in the Iberian Peninsula for 500 years has left an important legacy in terms of architectural techniques. The etymological origin of the term rammed earth, which in Portuguese is *taipa*, comes from the Arab word *tabíya*. Also, the origin of the word adobe is from the Arab words *tûb* or *atôb*, which means brick [6]–[8]. Looking at the Portuguese territory, it is possible to identify different regions with different earthen construction techniques, see Figure 2. Adobe and rammed earth are more common on the coast and on the south.

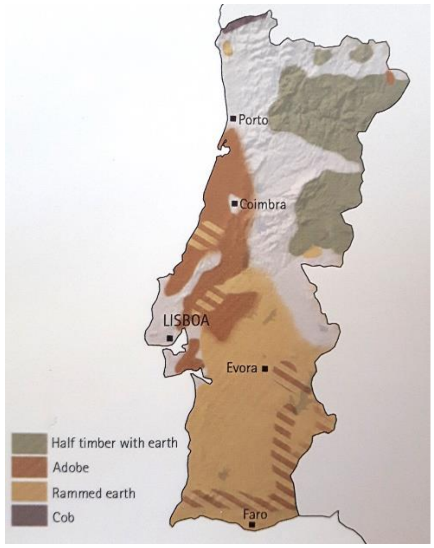


Figure 2: Distribution of different earthen construction techniques in Portugal [7].

The soil used for constructions is constituted by mineral components, in which clay particles act as a binder once the soil is mixed with water [9]. In this phase, it acquires plasticity and cohesion. After being in contact with air, it dries and develops stiffness because of which it can be used as a construction material. Moreover, the dried state can be reversible: once it is mixed with water, it transforms back into a deformable and workable material [10]. This reversibility has advantages in terms of maintenance and the ability to reuse the material, but it represents a challenge in terms of conservation and durability. Earthen buildings with low maintenance, when exposed to environmental agents show more severe damage due to regular contact with water. Cracks, vegetation, detachment, material loss, efflorescence, and rising damp are some of the main degradation phenomena associated with water action (Figure 3) [11]. On earthen walls, the damages caused by water can affect the whole structure, since the base is susceptible to water infiltration, while the top and the faces are more vulnerable to rainwater impact [12].

(a) (b) (c)

Figure 3: Examples of degradation phenomena in earthen constructions: (a) Biological growth in a vernacular house in Quito, Ecuador; (b) Material loss in Fahraj Castle, Yazd, Iran: (c) Cracking in earthen plaster, Huaca de la Luna, Peru.

In the last 30 years, the attention towards earthen heritage and its preservation has grown considerably. A significant number of publications, conferences, seminars, and round tables have been organized [13]. However, there is still a lack of knowledge regarding degradation phenomena and, consequently, on choosing the right treatment to be used [14], [15]. Following conservation theory and charters (essential as a background for any intervention in heritage) concepts as compatibility, reversibility and minimum intervention must be present as fundamental tools in the definition of any decision-making process [16], [17]. This means that most of the time, the selection of experimental tests to assess degradation phenomena and their causes, as well as the type of treatment to perform, is restricted to non-invasive techniques.

Under laboratory conditions, multiple tests can be performed to understand the mechanical, chemical and physical properties that allow the characterization of materials and structural components. Nevertheless, most of these tests are either destructive or semi-destructive. Hence it is crucial to perform non-destructive tests, not only to select the products but also to select the right approach to determine the degradation phenomena in earthen heritage.

1.2. Water absorption assessment in earthen materials

Any porous material can absorb water in the liquid state by capillarity action due to surface tension and the adsorption forces of the pore wall. Pore size and matrix of the pore system influences the mechanism of capillary water absorption [18]. This is valid for materials such as stone, brick, cement and lime mortars, where pore size and distribution are the main factors for capillarity parameters. However, for earthen materials, the presence of clay affects the way water uptake can be measured. The complexity of clay minerals and their interaction with water can be explained by its crystallography and ionic bonding. Looking at the basic formation of a clay mineral, it is usually constituted by layers of crystalline units of silicon-oxygen tetrahedron and/or aluminum or magnesium octahedron. Water is attracted by the negative charge in the clay surface, also by cations that connect layers, and by forming hydrogen bonding between the oxygen atoms of water and clay particles [19]. Due to this attraction, water encloses the clay particles in a phenomenon called double-layer; and as a result of this, clay acquires its plastic properties [19]. Furthermore, a critical aspect of clay behavior is related to its activity. The activity of clays was studied in 1948 by Skempton, who showed that it is possible to measure activity by calculating the ratio between the plasticity index and clay fraction content [20]. This author divided clay into three groups regarding their activity values as: (a) inactive clays (activity lower than 0.75); (b) normal clays (activity between 0.75 and 1.25); (c) active clays (activity higher than 1.25).

The most common clay minerals found in earthen constructions are kaolinite, with an activity value of approximately 0.33 (in the inactive range); illite, with 0.90 activity (normal clay), and montmorillonite, with 1.5 activity index (considered as active clay) [20]. Knowing the type of clay and its activity can give crucial answers concerning clay interaction with water. Sampling for clay identification in an earthen material is essential not only for an extended comprehension of its constitution, but also to draw an accurate intervention plan. Besides mineralogical and chemical characterization, water absorption parameters can also provide useful insights into an earthen surface behavior.

Conventional tests to evaluate water absorption by earthen materials that require a considerable amount of water to be performed become unviable. The literature concerning water absorption analysis in earthen-based specimens under laboratory conditions shows the use of capillarity tests [21], [22] in stabilized specimens. For example, if an adobe or rammed earth sample is prepared using a percentage of cement, lime or other stabilizers, it is possible to measure the capillarity coefficient [23], [24]. However, when dealing with non-stabilized earthen specimens, capillarity tests can produce irreversible damage and wrong results, since material loss index plays an important role (see section 4.1.). Even though changes in the test conditions can be done to improve the accuracy of measures, as using a paper filter and weighing the apparatus [25], the damage of the specimens can be avoided using a less invasive test, particularly when dealing with earthen heritage samples.

Other methods have been used in literature, such as placing specimens on top of a wet sand layer and registering the variation of weight [26]; or using a "wick" as an absorbent material in contact with the sample [27]. Although these methods seemed to work for the type of specimens studied, they have never been standardized and are complicated to replicate. Also, the Karsten tube method has been used [28]–[30] in laboratory and *in situ* conditions, showing that it can work, especially for evaluation of plasters. However, the amount of water required may represent a risk for more deteriorated samples.

Since a correlation between laboratory tests and conservation practice is essential, *in situ* tests are necessary to establish a validated set of results. In terms of non-destructive methods to access the water absorption coefficient in porous materials, only two tests can be performed: Karsten tube and contact sponge method [31]. As mentioned before, Karsten tube may have some limitations in terms of the amount of water necessary, as well as degradation of the material under study.

1.3. Surface protection of earthen materials

Water being one of the main causes of earthen buildings degradation phenomena, societies have developed preventive methods since ancient times, namely the use of natural products as coatings to protect the constructions [32]. Several of these methods are still used in some countries and they constitute a critical source of knowledge that should not be neglected. Table 1 presents a few examples of products used as a protective treatment.

Table 1: Examples of natural coatings or natural mixed products applied as a water repellent treatment in earthen buildings.

Country	***Water repellent***	***Application method***	***Reference***
Peru	San Pedro Cactus	Mixed with earthen mortar	[33]
Guinea	Karite butter	Mixed with earthen plaster	[34]
Ghana	Locust bean fruit	Applied on decorative earthen plaster	[34]
Cameroon	Fish oil	Mixed with earthen plaster	[34]
France	Linseed oil	Applied on top of earthen materials	[35]
Mali	Arabic gum	Mixed with earthen plaster	[36]

A series of recent interventions in earthen heritage have used cement plasters as a solution for water protection resulting in disastrous consequences. Cracking, detachment, and efflorescences are some of the main degradation phenomena induced in earthen structures when covered by this type of plaster [37]. Cementitious coatings are incompatible with earthen materials, since it blocks the normal humidity cycles and promotes more damage in the original layers [36]. Another practice is to use lime or gypsum plasters, since both show high compatibility with earth-based mortars compared with cement-based mortars, although periodic maintenance is necessary to assure better results [38].

Regarding natural coatings, most countries that still have the tradition of using earth as a construction material (houses and monuments) employ local products as a waterproof layer. By observing nature and passing this important empirical knowledge through generations, a series of recipes with a description of products and procedures have survived till nowadays [32], [35].

Besides natural products, a common recent practice is to apply synthetic coatings on earthen heritage interventions, mainly siloxane-based products [12], [39]. Although this procedure is widely studied for stone conservation, there is still a lack of scientific research for the case of earthen materials.

1.4. Contact sponge method

In literature, the contact sponge method is referred to as a valid non-invasive procedure to measure the initial rate of water absorption, giving important information on the behavior of the first layers of the analyzed material [40]. This technique was introduced by Tiano and Pardini in 2004, in Italy, as an alternative to measure the initial water uptake by porous materials, using a quick, non-expensive, non-invasive and friendly method [41]. Although this test gives data regarding the first layers of a porous material, it is also possible to assess the capillarity absorption factor. Besides this, understanding the behavior of superficial layers in the conservation field is a fundamental aspect, since they are more exposed to degradation phenomena, and can provide key information regarding material characterization, deterioration patterns, and reaction to environmental conditions [41]. The other advantages of this method are the possibility of using it both in laboratory and *in situ* conditions, avoids sampling historical surfaces, and can be used as a monitoring process for conservation treatments [40]. This is also essential for earthen heritage case studies since preventive conservation or maintenance is one of the most fundamental aspects of its preservation [14]. With such a simple and easy process like the contact sponge method, one can obtain crucial information about the conservation treatments and conservation assessment of a given cultural heritage building.

Nevertheless, Vandevoorde [41] states that the contact sponge method for stones can be used as an additional or complementary test to the Karsten tube method. However, if the amount of water plays an important role when aiming for a non-destructive test, which can result in material loss or increment of other degradation phenomena, then the contact sponge method is the most useful tool.

As mentioned before, besides material characterization, the contact sponge method can also be important to validate the efficiency of a product applied on a porous material surface [42]. A good example of this application is to characterize the efficiency and durability of a water repellent product applied to a surface, as it can provide solutions regarding initial water absorption of thinner top layers, where the repellent product acts.

2. Research aim

Water is one of the main causes of earthen material deterioration [43], [44]. As referred above, the presence and key role of clay in earthen constructions and its deep interaction with water affect decisively the cohesion among aggregates. Therefore, it is of paramount importance to understand the behavior and durability of earthen heritage when exposed to water (rain or high humidity levels), as well as the definition and evaluation of suitable testing techniques to measure water absorption.

The purpose of this paper is to validate the innovative use of the contact sponge method as a non-destructive technique to measure initial water absorption by earthen material and to further assess the efficacy of three water repellents (one synthetic and two natural).

3. Materials characterization

In order to understand the possibility and reproducibility of using the contact sponge method in unstabilized earthen materials, adobe and rammed earth specimens were prepared, see Figure 4a and Figure 4b, respectively.

(a) (b)

Figure 4: Specimens prepared for the experimental part: (a) Adobe; (b) Rammed earth.

Adobe blocks (3 x 15 x 7 cm^3) from Montemor-o-Novo (South of Portugal) were cut into cubes of approximately 7 cm size. In the case of the rammed earth samples, soil collected in Cercal (South of Portugal) was used to prepare specimens in the laboratory according to traditional techniques, which involved compressing the earth manually into a wood formwork creating cubes of approximately 10 cm, and then left to dry for four weeks. A total of twenty-three specimens for each construction technique were prepared: three specimens for capillarity test; five specimens as reference; and fifteen specimens for water repellents application (five specimens for each of the three water repellents). Specimens were characterized in terms of porosity, as showed in Table 2. Porosity is usually assessed through the immersion of the specimen in water. Since it is impossible to perform this test with earthen materials, porosity (n) was calculated as follows [19]:

$$n = \frac{e}{1+e} \tag{1}$$

The void ratio (e) was determined from the equation of the moist unit weight Υ (kN/m^3) and by applying an inverse formulation [19]:

$$\mathrm{e} = \frac{Gs(1+w)\Upsilon\mathrm{w}}{\gamma} - 1 \tag{2}$$

Where G_s is the specific gravity of soil solids (see Table 3), Υ_w is the unit weight of water (9.81 kN/m^3), and w is the moisture content.

Table 2: Specimens characterization.

	Moisture content	*Void ratio*	*ϒ (kN/m³)*	*Porosity*
Adobe	2.43	3.61	19.22	0.78
Rammed earth	0.64	1.13	20.08	0.53

A set of geotechnical, mineralogical, and chemical analyses were performed to characterize both soils in terms of particle size distribution (LNEC E196:1966 [45]) and specific gravity of soil solids (G_s) NP-83:1965 [46]. In addition, Atterberg limits, namely Liquid limit (LL), Plastic limit (PL), and Plasticity index (IP) (NP-143:1969 [47] were assessed. The modified Proctor test (LNEC E197:1967 [48]) was also performed, from which the maximum dry density after compaction (ρ_d) was obtained (only for rammed earth specimens). Finally, X-ray diffraction (XRD) and energy dispersive X-ray fluorescence (EDXRF) were performed as well. The results of all these tests are reported in Table 3.

XRD analysis was carried out using a Philips PW-1830 diffractometer with a Cu Kα radiation. The operation conditions were 40 kV, 50 mA, a step size of 0.02˚ 2θ in the 3-90˚ 2θ range, and a step time of 2.50 seconds. The samples were dried and grinded before testing. For EDXRF, three samples from each soil were analyzed using an ArtTAX X-ray spectrometer (Bruker), equipped with an Xflash (Si (Li)) detector, with 170 eV resolution, and operating with a molybdenum X-ray source. Elemental composition was acquired through an average of three different points, using a tube voltage of 40 kV, a current intensity of 600 µA, and live time of 180 s.

Table 3: Geotechnical, mineralogical, and chemical characterization of adobe and rammed earth soils.

	Particle size distribution	*G_s*	*Atterberg limits*	*ρ_d (g/cm³)*	*XRD*	*EDXRF*
Adobe	0% Gravel (>2 mm) 58% Sand (0.06 – 2 mm) 15% Silt (0.002 – 0.06 mm) 27% Clay (<0.002 mm)	2.63	LL 29% PL 18% IP 11%	-	Quartz, albite, pargasite	Al, Si, K, Ca, Cr, Mn, Fe, Cu, Zn, Ba, Pb
Rammed earth	41% Gravel (>2 mm) 34% Sand (0.06 – 2 mm) 13% Silt (0.002 – 0.06 mm) 12% Clay (<0.002 mm)	2.65	LL 45% PL 24% IP 21%	2.13	Quartz, feldspar, muscovite, goethite, and kaolinite	Al, Si, K, Ca, Cr, Mn, Fe, Cu, Zn, Ba

4. Experimental research

In the experimental campaign, two different measurements were done, namely capillarity and contact sponge method test. These tests were conducted on both reference (without any treatments) and surface treated specimens (water repellent treatment) of the two materials. The capillarity test was performed to understand the behavior of earthen materials in permanent contact with a given volume of water.

To evaluate the possibility of using the contact sponge to measure initial water absorption in earthen materials, two parameters were monitored, the superficial alteration due to contact with water (through visual inspection of both specimen surface and sponge to verify any material loss – see Figure 8) and the efficiency on measuring water absorption (comparing results before and after treatment).

4.1. Water absorption by capillarity

In order to understand the behavior of unstabilized earthen specimens in contact with a considerable amount of water, as well as to analyze the damage and material loss associated, a preliminary capillarity test was done. To determine the water absorption by capillarity, code EN15801 [21] was followed. Consequently, three adobe specimens and three rammed earth specimens were placed inside six separate plastic boxes with a bedding layer of absorbent paper on the bottom. Distilled water was added until saturation of the paper and each specimen was then placed on top of it. The specimens were weighed at regular time intervals. The test was done at laboratory conditions of 20 ˚C and 60% RH.

In the first 30 minutes, the adobe specimens showed an increase of mass by 3%, after three hours an increase of 8%, and after 24 hours the weight increased by 10% (this latter value remained stable until 72 hours). In the case of rammed earth specimens, after 30 minutes an increase of 1% of the mass was observed, after three hours by 3%, and 5% after 24 hours (this latter value remained stable until 72 hours). However, during the test, some difficulties in weighting the specimens were observed, due to material loss in both earthen techniques. A considerable amount of soil remained onto the bedding layer in the bottom of the box, making impossible to achieve accurate weight values and leading to misleading percentages of gained weight during the test. After 24 hours in contact with water, adobe specimens started to crack and rammed earth specimens showed deformation at the base, increasing the material loss. After 72 hours, the test was stopped, and the specimens were placed inside an oven at 100 ˚C to complete water evaporation. Specimens were again placed in laboratory conditions at 20 ˚C and 60% RH and weighted. The material loss was calculated by the difference of initial and final weight, with an average value of 6% for adobe specimens and 5% for rammed earth specimens.

Figure 5 illustrates the main differences between the initial and final states of the six studied specimens. Additionally, it is possible to observe the material attached to the bottom layer and the development of cracks.

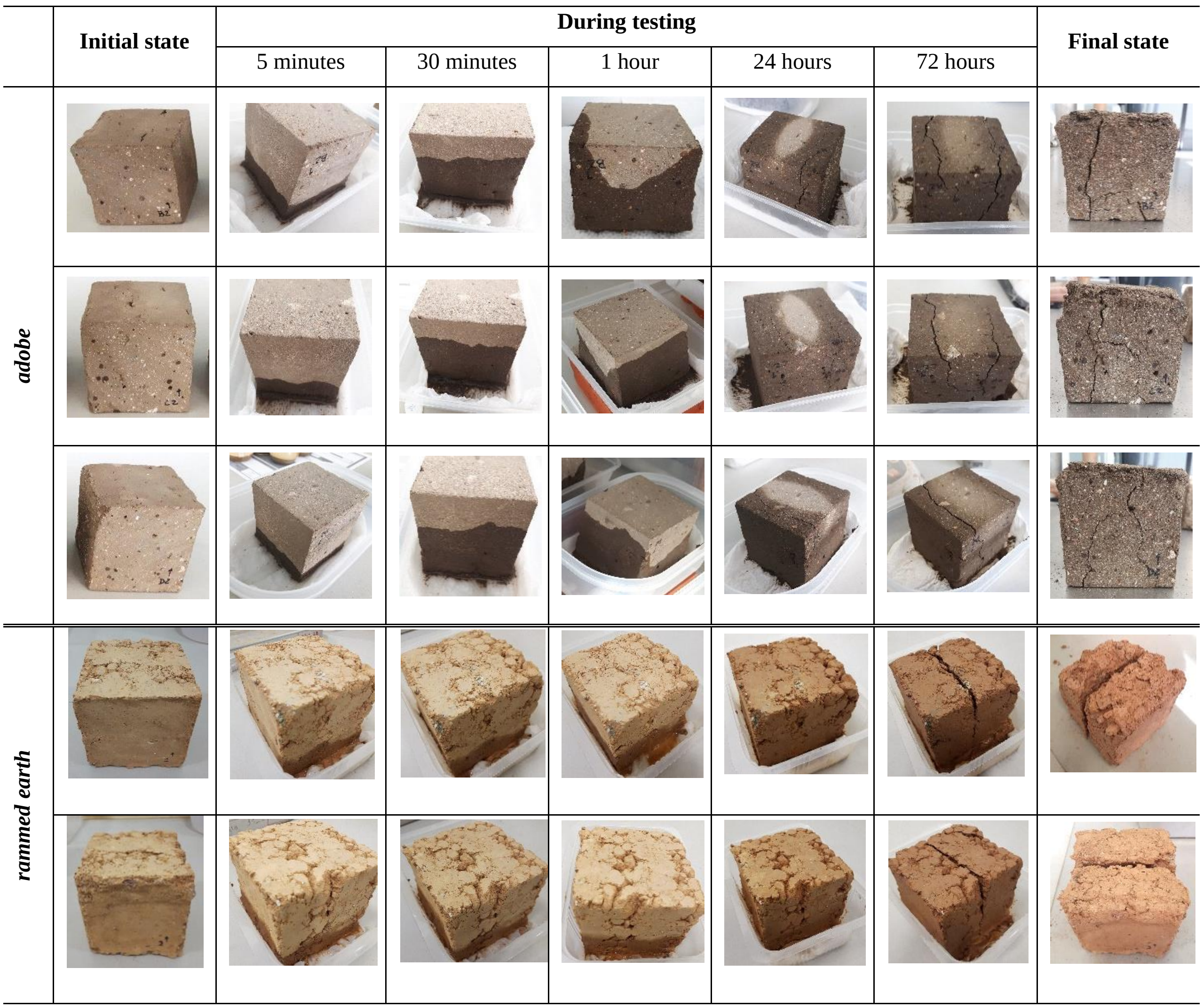


Figure 5: Different stages of capillarity test for each adobe and rammed earth specimen.

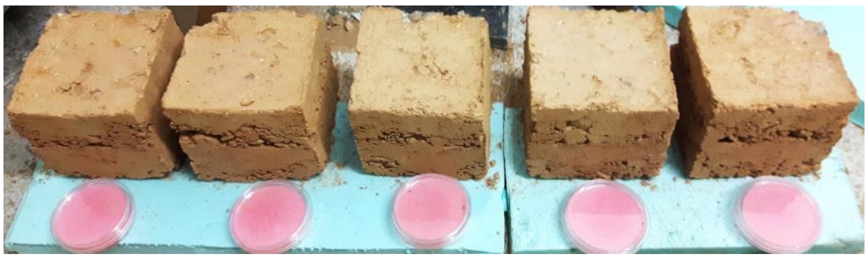
4.2. Contact sponge method

In order to not only assess the possibility of using contact sponge method to characterize initial water absorption on earthen materials but also to have a comparative study before and after treatment, three different water repellent products were applied on both adobe and rammed earth specimens. The selection of water repellent was based on the most commonly used products, according to the literature [15], [49], [50]. Therefore, one synthetic and two natural products were chosen: (a) commercial water repellent with a base of organosiloxane oligomers (Silo 112 CTS®, Spain); (b) linseed oil; (c) beeswax (prepared in a solution of 3% of turpentine).

Two layers of each product were applied on one surface (exposed surface in a wall) using a brush, to simulate a real case scenario. Each product was applied on five specimens of adobe and five specimens of rammed earth, having also five specimens from each building technique as a reference. The contact sponge test was performed seven days after applying the products to guarantee their curing and stabilization to environmental conditions.

Contact sponge method was performed following the Italian Standard UNI 11432 [51], using five sponges and capsules for each set of five specimens tested (Figure 6). Preliminary tests were done in order to define the time in which the sponge must be in contact with the specimen (should be between 30 seconds and 3 minutes, according to the standard). For this experiment, 60 seconds of contact time was chosen. Following the procedure, 5 ml of distilled water was poured on the top of each sponge. The weight of the sponge inside the capsule is taken before and after contact with each specimen. It is also important to mention that no pressure was applied on the sponge, since it is confined inside the plastic capsule and the experiment was always carried out in the vertical position to simulate *in situ* conditions (Figure 7). All specimens were kept inside a controlled environmental temperature of 20 ± 5˚C and relative humidity of 60 ± 5%. Likewise, contact sponge tests were also carried out in the same conditions.

(a)



(b)

Figure 6: Contact sponge method apparatus: (a) adobe specimens; (b) rammed earth specimens.

(a) (b)

Figure 7: Example of contact sponge test procedure: (a) adobe specimen; (b) rammed earth specimen.

5. Results and discussion

Based on the visual inspections of specimens' surface both adobe and rammed earth samples showed no evidence of material loss, deformation nor cracking. Moreover, through sponge inspection after performing the test, it was also observed the absence of any residual material on it. Additionally, water is barely absorbed by the specimens where products were applied. Observing the examples in Figure 8, reference specimens exhibit a clear mark by the contact between the wet sponge and the earthen material, whereas in case of specimens with water repellent treatment this mark is less evident or even non-existent.

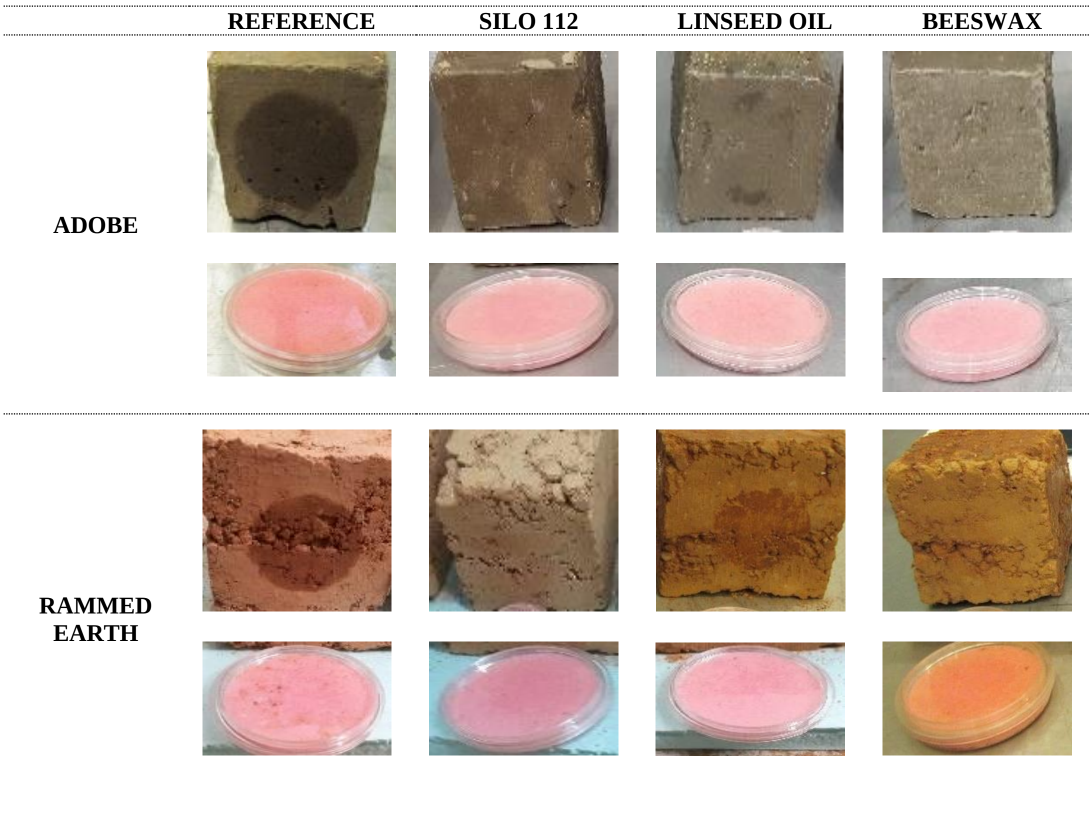
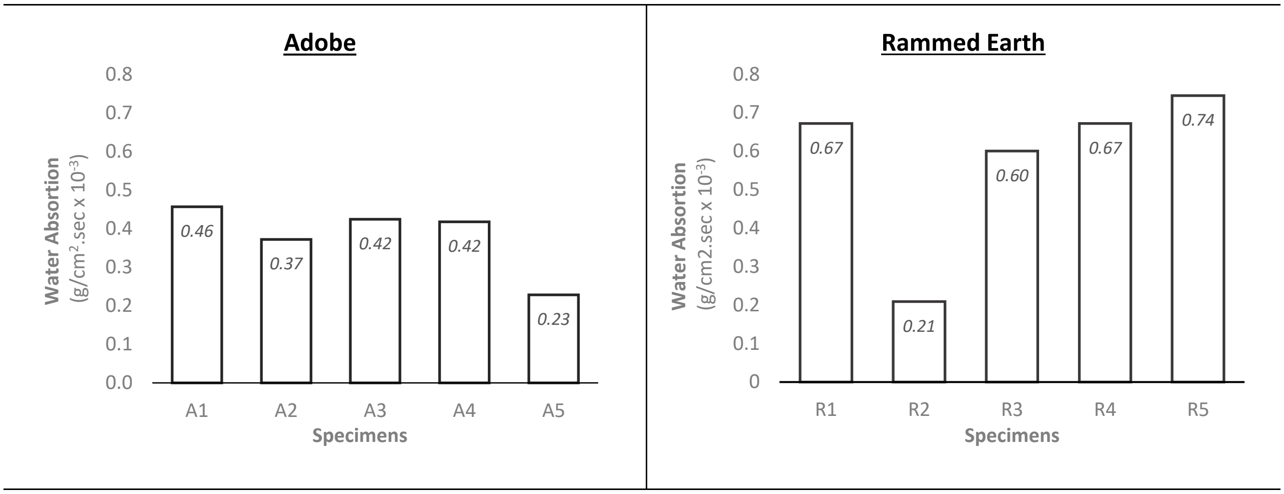


Figure 8: Visual inspection of adobe and rammed earth surfaces and sponge after performing the test.

According to the results of the contact sponge test, Figure 9 reports the data of reference specimens, i.e., without any superficial treatment. In general, adobe specimens absorb less water than rammed earth specimens, which can be explained by the presence of less active clay. Besides that, the results show that for each earthen technique, one of the specimens clearly absorbed less water than the others. This may be due to irregularities of the surface, for instance, a greater number of voids, leading to less absorption of water. So, according to these data, it is possible to conclude that the surface plays an important role regarding the homogeneity of results. The average values of water absorption were thus computed excluding the two outliers, resulting in 0.42 g/cm^2.sec (x10^{-3}) for adobe (CoV of 8%) and 0.67 g/cm^2.sec (x10^{-3}) for rammed earth (CoV of 9%) specimens.

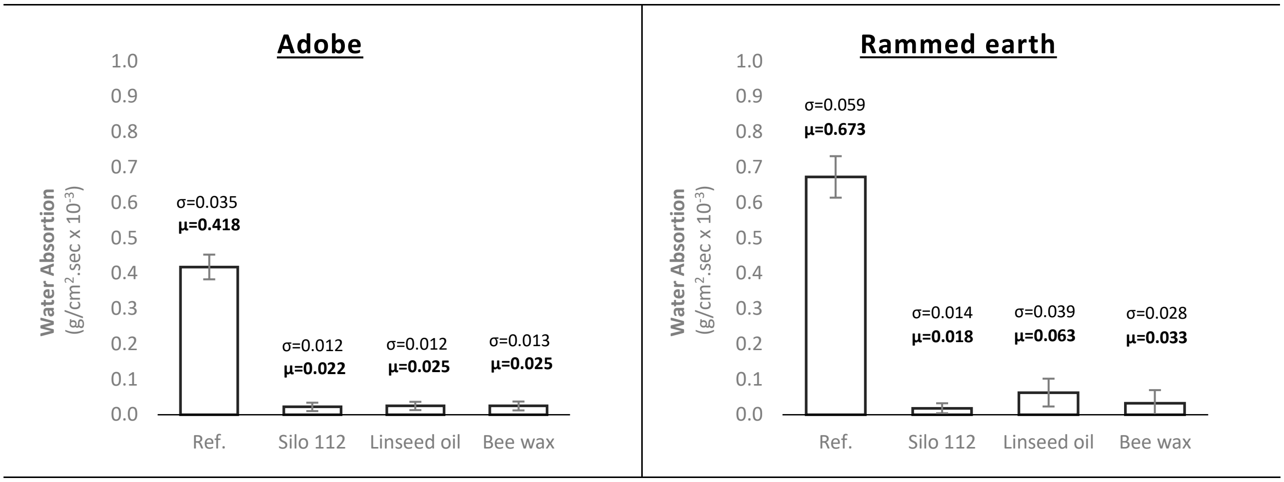


(a) (b)

Figure 9: Water absorption for reference specimens: (a) adobe (A1 – A5); (b) rammed earth (R1 – R5).

After applying the three water repellent products, the contact sponge method was performed under the same conditions and the results obtained are shown in Figure 10. As expected, specimens with water repellents revealed a reduction in water absorption, thus suggesting the effectiveness of these treatments. In the case of adobe specimens, all three treatments showed a similar reduction in water absorption, with a decrease of about 94%. This value represents not only a significant improvement in the water repellence capacity of the adobe surface, but it also indicates how efficient the contact sponge method can be. Also, in rammed earth specimens, the same impressive results are observed. There is a decrease of 97% of water absorption after applying Silo 112, 91% in the case of linseed oil, and 95% with beeswax.

Small differences between the results of each product applied on different earthen techniques (adobe and rammed earth) may be due to surface and matrix interaction, penetration level and chemical bonding. However, results show that it is possible to measure water absorption with accuracy, even when dealing with such a heterogeneous material as earth.



(a) (b)

Figure 10: Contact sponge test results on specimens after treatment with water repellent products on: (a) adobe; (b) rammed earth (with the indication of average (μ) and standard deviation (σ) values).

6. Conclusions

Water absorption by any porous material is an important parameter to access, especially when dealing with cultural heritage buildings. Though in most cases like stone or mortar materials, the amount of water required to perform a capillarity test is a neglected factor, it plays an essential role in earthen materials. Results showed that water uptake by the capillarity method caused severe consequences in the material state. Material loss, cracking and physical alteration were observed in all tested specimens. Moreover, assessing the real water absorption curve became almost impossible due to the considerable amount of material loss (6%), which can mislead the results.

Through a set of laboratory tests, it was possible to conclude that the contact sponge method can be safely used in earthen materials, without changing the material nor deteriorating its surface. The contact sponge method can be applied in earthen materials or earthen heritage superficial layers since it does not represent any risk or originate any major deterioration phenomena. Furthermore, this test also proved to be efficient in analyzing the effect of water repellent treatment.

The three water repellents tested for this study showed to work as a hydrophobic barrier since all specimens reduced significantly (more than 90%) the absorption of water by the adobe and rammed earth specimens. It is also important to notice the impressive result observed from the natural products when compared with the synthetic product. Both linseed oil and beeswax demonstrated similar performance regarding water repellency as the commercial Silo 112, revealing their capacity as an alternative sustainable solution to synthetic products.

For conservation purposes and especially in maintenance plans, by using this simple tool in an earthen heritage site, one can obtain important outputs about the efficiency of a given surface treatment over time. It was possible to observe, that surface irregularities are an important factor to consider when using this method. The sponge should be completely in contact with the surface. To avoid ambiguous conclusions, it is essential to perform contact sponge test on a considerable number of specimens or areas (if dealing with a case study), so outliers can be identified clearly. Since adobe and rammed earth are traditional and hand-made construction materials, there is no uniformity between samples or even a wall, so performing the tests in a large number of specimens (laboratory) or spots (*in situ*) is highly recommended.

Nevertheless, more research data is required to understand if the contact sponge test can be used for other types of soils and construction techniques different from the ones approached in this research. Moreover, future work should also handle with case studies and include deteriorated surfaces.

Acknowledgements

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